THE ROYAL AUSTRALIAN CHEMICAL INSTITUTE

2010
AUSTRALIAN NATIONAL CHEMISTRY QUIZ

Senior Division
Year (12)

THURSDAY 22 JULY, 2010

Sponsored by
CHARLES STURT UNIVERSITY

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RULES

1. Do not open the book until told to do so by your teacher. The quiz consists of 30 multiple choice questions to be answered in 1 hour.
2. Calculators and rough-working paper are permitted.
3. Record all your answers on the computer sheet provided, in the way indicated on back of book using a **soft lead pencil.**

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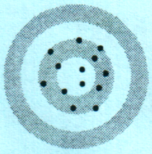
Information

Relative Atomic Masses: H = 1.008, C = 12.01, N = 14.01, O = 16.00, S = 32.0, Cl = 35.45, Ca = 40.08, Fe = 55.85

Question 1

Scientists use the terms "accurate" and "precise" when interpreting experimental data. "Accurate" data are close to a true value. "Precise" data are consistent and can be stated to a large number of significant figures.
Which of the following targets represents data with low accuracy but high precision?

A.



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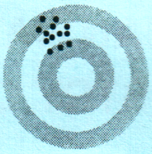

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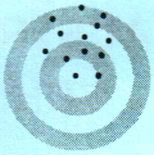

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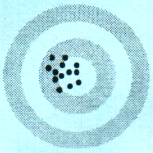


Question 2

Iodine was discovered in 1813 by Bernard Courtois, who processed seaweed to extract Chilean saltpetre, $NaNO_3$. The metallic vessels used to extract $NaNO_3$ from seaweed ashes corroded rapidly. To determine why, concentrated sulfuric acid was added to the ashes. This produced enough heat to cause the violet-coloured gas, iodine, to form. It is now known that seaweeds, such as kelp, concentrate iodide ions from seawater in their leaves.
Two reactions with sulfuric acid produce iodine:

$$2\ NaI + 2\ H_2SO_4 \rightarrow Na_2SO_4 + I_2 + SO_2 + 2\ H_2O$$
$$8\ NaI + 5\ H_2SO_4 \rightarrow 4\ Na_2SO_4 + 4\ I_2 + H_2S + 4\ H_2O$$

Both of these reactions are definitely

A. acid-base.
B. acid-base and exothermic.
C. redox and exothermic.
D. redox.

Question 3

A single atom of a new chemical element has been made by German and Japanese teams. Particle accelerators fired zinc atoms at lead atoms causing their nuclei to fuse, forming an atom of ununbium, element 112. It lies directly below zinc, cadmium and mercury in the periodic table.

It can be inferred that the new element is

A. a silver coloured metal that is liquid at room temperature.
B. a dense covalent network solid that forms an oxide of formula X_2O.
C. a very dense metal that forms a chloride compound of formula MCl_2.
D. a radio-active metal that should be found naturally in its elemental form.

Information for Questions 4 and 5

Spectacle wearers have the option of purchasing lenses that are *photochromic*; that is, they darken rapidly when the wearer goes into sunlight and lighten rapidly on returning inside, even if the wearer is beside a window. The photochromic chemical, oxazine, changes form as shown:

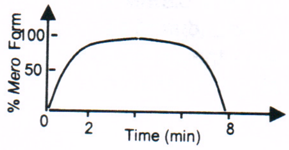
$$\underset{(light)}{\textit{Spiro}\text{-oxazine}} \overset{UV}{\rightleftarrows} \underset{(dark)}{\textit{Mero}\text{-oxazine}} \qquad \Delta H = -ve$$

Within one minute 50% of the oxazine has changed form, by two minutes about 80% and by seven minutes more than 99% oxazine conversion occurs.

Question 4

Which of the following graphs best illustrates the percentage conversion between light and dark forms of oxazine when a person wearing photochromic lenses outside, goes inside for a few minutes, and then returns outside?

A.



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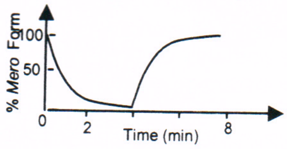

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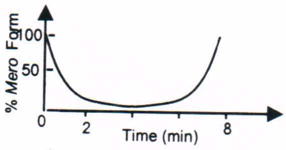

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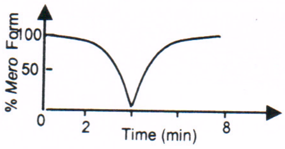


Question 5

From the given information, it can be deduced that photochromic lenses

A. are darker in cold temperatures than in hot temperatures.
B. would work well as sunglasses in a car.
C. eventually stop changing colour due to breakdown of the oxazine molecule.
D. after ten minutes of sun exposure, no oxazine molecules change form.

Question 6

Car batteries use sulfuric acid solution as their electrolyte. When fully charged, the acid has a concentration of 4.1 M. A hydrometer, which measures the density of the solution, can be used to check the cell's charge. 18 M sulfuric acid has a density of 1.8 g mL^{-1}. A fully charged cell should have a density closest to

A. 1.61 g mL^{-1}. B. 1.41 g mL^{-1}. C. 1.18 g mL^{-1}. D. 0.41g mL^{-1}.

Question 7

A student conducts analysis of an unknown solution and obtains the following results:

- Reacts with HCl, NaOH, $Pb(NO_3)_2$, $Ba(NO_3)_2$, Na_2CO_3 solutions
- No reaction with H_2SO_4, $AgNO_3$

The likely identity of the solution is

A. Ag_2SO_4 B. $CaCl_2$
C. $BaCl_2$ D. $CuSO_4$

Anion	**Soluble Cations**	**Cations forming Precipitates**
NO_3^-	all	-
Cl^-	most	Ag^+, Pb^{2+}
SO_4^{2-}	most	Ba^{2+}, Ca^{2+} Ag_2SO_4* $CaSO_4$*
CO_3^{2-}	Na^+, K^+, NH_4^+	most
OH^-	Na^+, K^+, Ba^{2+}	most, $Ca(OH)_2$*

* These compounds are slightly soluble

Question 8

Oxides of nitrogen are significant contributors to air pollution in cities and include NO, NO_2 and N_2O_4. They are often formed during the combustion of fossil fuels in vehicle engines and power stations, by reacting with ozone, O_3, and through the action of sunlight. Significant energy changes occur during these reactions. The enthalpy of a reaction is the difference between the enthalpies of formation of substances present in the equation. The enthalpy of formation of a substance is the energy absorbed or released when one mole of the substance forms from its elements in their standard states at 25°C.

Molecule	O	O_2	N_2	NO	NO_2	N_2O_4
Enthalpy of Formation kJ/mol	+249	0	0	+90	+33	+9

Which of reactions listed has the most endothermic value?

A. $N_2 + O_2 \rightarrow 2\ NO$ B. $2\ NO_2 \rightarrow N_2O_4$
C. $2\ NO + O_2 \rightarrow 2\ NO_2$ D. $NO_2 \rightarrow NO + O$

Question 9

Aminoethane sulfonic acid zinc complex, $Zn(C_2H_2NO_3S)_2$, is a patented anti-hepatitis agent. Its preparation from sulfonic acid, which is complex and involves many steps, can be summarised by the equation:

$$HSO_2OH + 2Y + ZnSO_3 + 2\ C_2H_5OH + 2\ O_3 \rightarrow Zn(C_2H_2NO_3S)_2 + 8\ H_2O$$

The identity of molecule *Y* is

A. ammonia, NH_3. B. ammonium hydroxide, NH_4OH.
C. ammonium nitrate, NH_4NO_3. D. nitric acid, HNO_3.

Question 10

Hair has a negative surface charge due to its amino-acid composition. Shampoos work by dissolving oils and dirt allowing them to be washed away. Conditioners adhere to the hair making it feel smoother and fuller. Both shampoos and conditioners are composed of a charged "hydrophilic" head and a non-polar "hydrophobic" hydrocarbon tail.
Which combination would work best for a shampoo and a conditioner?

	A.	**B.**	**C.**	**D.**
Shampoo	⊖〰〰〰	⊖〰〰〰	⊕〰〰〰	⊕〰〰〰
Conditioner	⊕〰〰〰	⊖〰〰〰	⊕〰〰〰	⊖〰〰〰

Information for Questions 11 and 12

Solubility product, K_{sp}, is an equilibrium constant calculated from the product of ionic concentrations present in a saturated solution. For example, stirring solid Ag_2CrO_4 into water forms a saturated solution at 6.69 x 10^{-5} M. In solution are Ag^+ ions at 1.34 x 10^{-4} M (2 x 6.69 x 10^{-5} M) and CrO_4^{2-} ions at 6.69 x 10^{-5} M. The K_{sp} expression, $K_{sp}(Ag_2CrO_4) = [Ag^+]^2 \times [CrO_4^{2-}]$, yields a value of 1.2 x 10^{-12}. This corresponds to a solubility of 0.022 g Ag_2CrO_4 per litre.

Solubility Products, K_{sp}, of some substances

Substance	**K_{sp}**	**Substance**	**K_{sp}**
$CaCO_3$	4.5 x 10^{-9}	$MgCO_3$	5.1 x 10^{-5}
CaF_2	3.9 x 10^{-11}	MgF_2	1.00 x 10^{-8}

Question 11

Carbonate ions in solution are easily detected by adding $CaCl_2$ solution, which forms $CaCO_3$ as a precipitate. If CO_3^{2-} ions are present at 0.0001 M, what minimum concentration of $CaCl_2$ would cause $CaCO_3$ to precipitate?

A. 1.0 x 10^{-4} M B. 7.5 x 10^{-4} M C. 4.5 x 10^{-5} M D. 6.7 x 10^{-5} M

Question 12

When salt-rich water evaporates in subterranean caves, mineral crystals form. If water rich in calcium, magnesium, fluoride and carbonate ions gradually evaporates, which two minerals would form crystals first?

	A.	**B.**	**C.**	**D.**
1st crystals formed	CaF_2	CaF_2	$CaCO_3$	$CaCO_3$
2nd crystals formed	$CaCO_3$	$MgCO_3$	CaF_2	MgF_2

Question 13

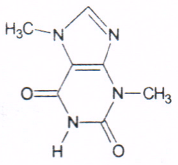
Spider silk is one of the toughest fibres known, but injecting it with a metal can make it up to ten times as strong. Scientists have discovered that the hard jaws, claws and stingers of insects are made from silk-like substances laced with metal ions. They have also found that firing beams of ionised titanium compounds at silk increases its strength and stretchiness. Artificial tendons, made from metal-strengthened collagen, are a possible application of this technology.

Adding metal to the fibre is most likely to increase strength because

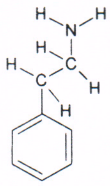
A. more van der Waals forces are created between amino-acid polymers in silk.
B. hydrogen bonds are replaced by ionic bonds between polymers.
C. metals react with the spider silk's protein causing additional cross-links between polymers.
D. the metal's low electronegativity polarises nearby atoms, increasing attraction.

Information for Questions 14, 15 and 16

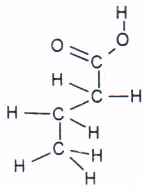
Everyone loves chocolate. It is a high-energy food made from processed cocoa beans, sugar and, usually, milk solids. It contains a wide variety of substances including glucose, theobromine, caffeine, phenylethylamine and butanoic acid. Theobromine and caffeine are stimulants. Phenylethylamine is said to be responsible for feelings of well-being, as it has a direct effect on the brain. Butanoic acid, in small amounts, adds to the richness of the flavour.



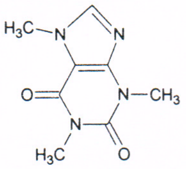
Theobromine



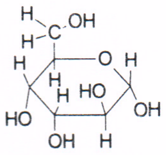
Phenylethylamine



Butanoic acid



Caffeine



Glucose

Question 14

The % mass of nitrogen in theobromine, $C_7H_8N_4O_2$, (molar mass 180.16) is

A. 19.05 B. 31.10 C. 32.56 D. 56.04

Question 15

What is the molecular formula for caffeine?

A. $C_8H_{10}N_4O_2$ B. $C_8H_9N_4O_2$ C. $C_7H_9N_4O_2$ D. $C_4H_5N_2O$

Question 16

Which substance has the closest molecular mass to that of theobromine?

A. Phenylethylamine B. Butanoic acid C. Caffeine D. Glucose

Information for Questions 17, 18 and 19

Acid mine drainage, *AMD*, affects water quality throughout the world by producing water of extremely low pH, such as at Iron Mountain in the USA, where water of pH –3.6 has been recorded. The interaction of oxygen and water with exposed surfaces of pyrites, FeS_2, produces acid solution:

$$4\,FeS_2 + 15\,O_2 + 2\,H_2O \rightarrow 4\,Fe^{3+} + 8\,SO_4^{2-} + 4\,H^+$$

The ultra-low pH conditions cause the solution of sulfide-containing minerals that release heavy metals like Cd, Ni, As, Cu and Zn, which also deteriorate the water quality. One method of treatment is to add slaked lime, $Ca(OH)_2$, to neutralise the water. More recently the use of sulfate reducing bacteria, *SRB*, has been used to improve water quality. *SRB* convert organic matter, "CH_2O", to hydrogen carbonate ions and the H_2S produced then precipitates heavy metal ions, M^{2+} as sulfide compounds.

$$SO_4^{2-} + 2\,\text{"}CH_2O\text{"} \xrightarrow{SRB} H_2S + 2\,HCO_3^-$$

$$H_2S + M^{2+} \rightarrow MS(s) + 2\,H^+$$

Questions 17

At pH –3.6, the molar concentration of H^+ ions caused by *AMD* is

A. $10^{-3.6}$ M. B. 6×10^{-3} M. C. 6×10^{3} M. D. 3980 M.

Questions 18

1.0 L sample of mine drainage water was collected and found to have a pH = 0. What mass of slaked lime, $Ca(OH)_2$, would required to neutralise this sample?

A. 0 g. B. 37.0 g. C. 74.0 g. D. 148 g.

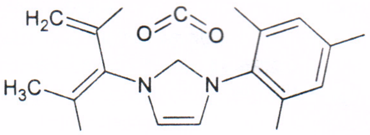
Questions 19

Which statement is true about reducing the impact of *AMD*?

A. The use of *SRB* decreases the amounts of heavy metals in solution.
B. Using slaked lime would be impractical to neutralise industrial volumes of *AMD* of pH –3.6.
C. Restricting oxygen access to mining residues reduces the amount of acid produced.
D. All of the above.

Question 20

Scientists in Singapore have found a way of converting the greenhouse gas carbon dioxide into methanol at room temperature. The methanol can then be used as a clean-burning fuel. The process uses *N*-heterocyclic carbene (*NHC*) as a catalyst, which appears to change the shape of the CO_2 molecule as shown, enabling it to react with hydrosilane, R_3SiH.



N Heterocyclic Carbene

$$CO_2 \xrightarrow[NHC]{R_3SiH} CH_3OH$$

Changing the shape of the CO_2 would assist it to react because bending

A. the molecule breaks the C=O double bond.
B. provides the activation energy necessary for the reaction.
C. increases the chances of $R_3Si\text{-}H$ colliding with the C atom.
D. lowers the energy required from a collision, thereby increasing the number of successful collisions.

Information for Questions 21 and 22

Lithium-ion batteries are used in the latest gadgets. They can be recharged repeatedly with little degradation, but recharging takes time. In a new development, one electrode is composed of 50 nm diameter balls of lithium iron phosphate, $LiFePO_4$, the other a graphite rod. Recharging causes the balls to release lithium ions rapidly, which migrate to the graphite rod. Discharging produces lithium ions at the graphite electrode, which the balls re-absorb.

Questions 21

This new cell should recharge more rapidly than a cell with conventional electrodes because

A. the small balls can move faster from one side of the cell to the other, increasing current flow, and so decreasing recharge time.
B. the small balls increase the surface area available for reaction, thereby increasing the rate of recharge.
C. the electrolyte ions have less distance to travel between anode and cathode hence increasing current flow and recharge rate.
D. both B and C are true.

Questions 22

It can be deduced that the redox pairs for this cell are Li^+/Li and Fe^{3+}/Fe^{2+}.
(**E°/V**: $Li^+/Li = -3.05$; $Fe^{3+}/Fe^{2+} = +0.770$)

The cell voltage and the polarity of the $LiFePO_4$ electrode during discharge are:

	A.	**B.**	**C.**	**D.**
Cell Voltage	3.82	3.82	2.28	2.28
$LiFePO_4$ Polarity	Positive	Negative	Positive	Negative

Question 23

Many solutions contain more than one solute. A student mixed 20.00 mL of 0.0500 M $CuCl_2$ with 30.00 mL of 0.0400 M $AlCl_3$ and 50.00 mL of 0.100 M NaCl. 0.100 M $AgNO_3$ was used to determine the amount of chloride ions present in the solution, using K_2CrO_4 as a precipitation indicator.

What is the volume of the titre?

A. 10.60 mL B. 14.40 mL C. 20.00 mL D. 21.20 mL

Question 24

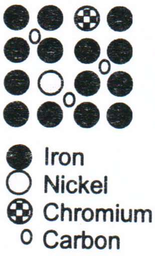
The noble gases (He, Ne, Ar, Kr and Xe) were first identified in the 1890's by William Ramsay using spectroscopic methods. They are quite unreactive, with no naturally occurring compounds known. Much more recently some compounds of noble gases have been synthesised.

The compound most likely to be synthesised would be

A. XeF_6, because F is highly electronegative enabling attraction of valence electrons from the large Xe atom.
B. HeO, because valence electrons in He can be easily shared with an O atom.
C. HeXe, because Xe (core charge 8+) attracts valence electrons of He (core charge 2+) strongly, enabling the formation of a single covalent bond.
D. NeF_6, because both elements are of similar size.

Question 25

The alloy steel is the most used "metal" in the world. Steel is an *interstitial lattice* with the much smaller C atoms filling spaces between the Fe atoms, as shown in the diagram. In stainless steel, chromium and nickel atoms also replace Fe atoms in a *substitution lattice*, also shown. Changing the composition of the alloy changes its properties.



From structural considerations only, it could be predicted that the stainless steel's

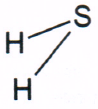
A. resistance to corrosion increases as chromium content increases.
B. strength increases but conductivity decreases as carbon content increases.
C. density decreases with increased carbon content.
D. brittleness increases as nickel content increases.

Question 26

The polarity of a molecule depends on its basic shape and composition, which are caused by the arrangement and electronegativity of the specific atoms present. Polarity affects many properties including the substance's solubility in different solvents.

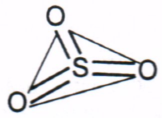
Which of the following would be most soluble in water?

A. H_2S



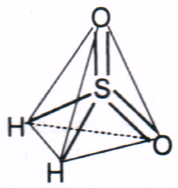
Angular

B. SO_3



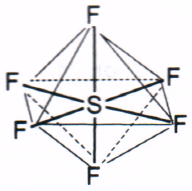
Triangular Planar

C. H_2SO_2



Tetrahedral

D. SF_6



Octahedral

Question 27

Electrolysis is used as a method to remove body hair permanently. A metal needle is pushed into a hair follicle and a current is applied several times for ten seconds, after which the hair is removed. Electrolysis of the body's cellular fluids, essentially sodium chloride solution, forms sodium hydroxide which destroys the hair follicle. Hydrogen is a by-product at the negative electrode.

Which combination of equations best explains this process?

	Cathode	**Anode**
A.	$2\ Cl^- \rightarrow Cl_2 + 2\ e^-$	$2\ H_2O + 2\ e^- \rightarrow 2\ OH^- + H_2$
B.	$2\ H^+ + 2\ e^- \rightarrow H_2$	$2\ H_2O \rightarrow 4\ H^+ + O_2 + 4\ e^-$
C.	$2\ H_2O + 2\ e^- \rightarrow 2\ OH^- + H_2$	$2\ Cl^- \rightarrow Cl_2 + 2e^-$
D.	$2\ H_2O \rightarrow 4\ H^+ + O_2 + 4\ e^-$	$2\ H^+ + 2\ e^- \rightarrow H_2$

Question 28

Several useful gases are obtained from the fractional distillation of liquefied air. Liquefied air is produced by allowing highly compressed gases to expand rapidly, cooling it below the boiling points of the major gases present.

Gas	Nitrogen	Argon	Oxygen
Boiling Point (°C)	–196	–186	–183

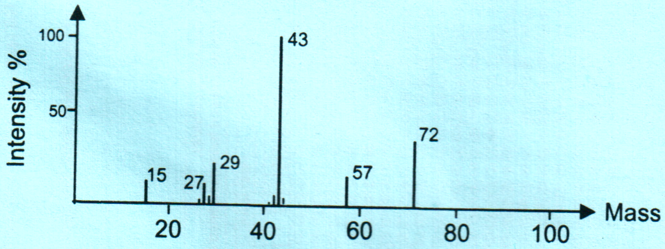
To what minimum volume must 100 L of air originally at 100 atm pressure and 25°C be expanded before **any** gas liquefies?

A. 6140 L B. 3020 L C. 2920 L D. 2580 L

Question 29

Mass spectrometry is particularly useful when identifying organic molecules, and has been used to help identify sporting drug cheats. Samples are introduced into a spectrometer where molecules are ionised by electron removal. Molecular fragmentation occurs when bonds break, resulting in ions of smaller mass than the original molecule. For example, butane, C_4H_{10}, would commonly produce fragments of mass 58 ($C_4H_{10}^+$), 43 ($C_3H_7^+$), 29 ($C_2H_5^+$) and 15 (CH_3^+).

The mass spectrum of an unknown substance is shown below. The mass of each key peak is shown.



Which compound is most likely to have this mass spectrum?

A. CH_3COCl

B. $CH_2CHCH_2CH_2OH$

C. CH_3CH_2COOH

D. $CH_3COCH_2CH_3$

Question 30

One commercial method of producing sulfur dioxide, SO_2 is by roasting iron pyrites, FeS_2, in air. The equation for the reaction is:

$$4\,FeS_2(s) + 11\,O_2(g) \rightarrow 2\,Fe_2O_3(s) + 8\,SO_2(g)$$

If 100.0 g of pyrites is roasted in 100.0 g of oxygen gas, the mass, in g, of excess reagent is

A. 9.71 g of O_2.

B. 26.6 g FeS_2.

C. 26.6 g of O_2.

D. 73.3 g FeS_2.

Questions compiled and typeset by David Miller, Toowoomba Grammar School, Toowoomba, Qld, with thanks for advice received from Lyndon Smith, Perth, Western Australia; Martin Sormus, Wollongong, NSW; Andrew Eaton, Tahmoor, NSW; Elaine Bergmann, Ipswich, Qld and Susan Margan, Epping, NSW. Printed by Brian Burke Printing, Bathurst, NSW.